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Mechanical Properties of Aerojet, Thiokol, and JA2 High-Energy Gun Propellants at 1.5 m/s Deformation Rate

by Michael G. Leadore

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Mechanical Properties of Aerojet, Thiokol, and JA2 High-Energy Gun Propellants at 1.5 m/s Deformation Rate

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Abstract

Five lots of high-energy gun propellants were tested in uniaxial compression at temperatures of 21°, 63°, and −32 °C. The materials were taken to ~60% strain using a deformation rate of 1.5 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

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1. Introduction

The following is the U.S. Army Research Laboratory's (ARL's) report of the material test systems (MTS) servo-hydraulic tester (SHT) high-rate mechanical response of one lot of Aerojet 3744 lot no. 8194D, and three lots of Thiokol lot no. JA-1835-2-01, JA-1835-2-02, and JA-1835-2-03. The Aerojet and Thiokol materials are Future Combat System candidate (Figure 1) gun propellants (test sets 65-80 Fiscal 01). A production lot of JA2 lot no. HCL93-J014-001 was also tested using similar test conditions for comparative purposes.

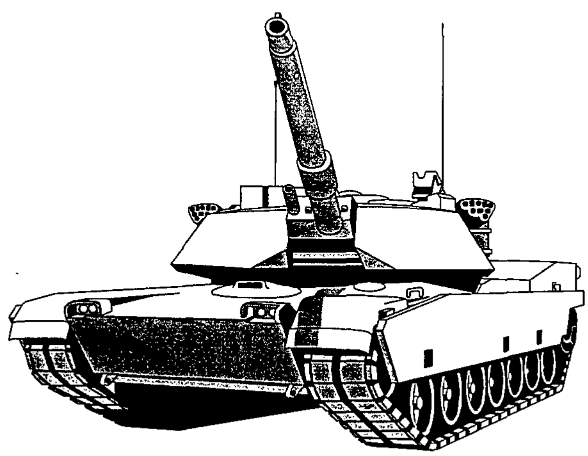

Figure 1. M1 Abrams tank with 120-mm gun.

2. Background

ARL received four lots of Aerojet and Thiokol gun propellants (Figure 2) from Ms. Thelma Manning of the U.S. Army Armament Research, Development, and Engineering Center (ARDEC). The Aerojet next-generation high-energy propellant was manufactured in a mixer and extruded thermally into a solid-sheet configuration. The sheet material had a thickness of ~1.3 mm. Several sheets from the lot of experimental gun propellant were shipped to Dr. Robert Lieb of ARL. The Thiokol lots were extruded into solid-stick configuration and also shipped to Dr. Lieb. Also, a production lot of JA2 granular propellant was procured from Aberdeen Proving Ground (APG) for comparison testing. All of these materials were tested during August 2001 for high-rate uniaxial compression mechanical response evaluation.

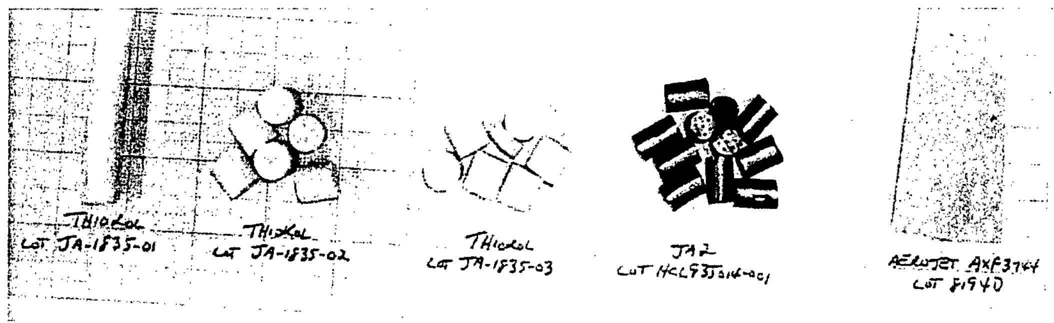

Figure 2. Aerojet, Thiokol, and JA2 lots of gun propellants as received.

3. Approach and Results

The Aerojet propellant was received in solid-sheet form and was without perforations. The lot was cut into test specimens with a length-to-diameter (L/D) ratio of 0.96.

Specimen preparation was accomplished using a 12.7-mm-diameter hole punch. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis. The Thiokol lots were received as solid-stick with a diameter of 12.68 mm and were cut into test specimens using a double-bladed diamond saw. The JA2 lot was granular with a diameter of 9.80 mm and was also cut using a diamond saw.

MTS SHT mechanical properties tests [1–7] were conducted on several specimens under each test condition (Figure 3). Strain rates of 125.0 s^{-1} were achieved. The specimens were taken to failure at ambient pressure to ~50% end strain while conditioned at temperatures of 21°, 63°, and −32 °C. The stress at failure, strain at failure, modulus, failure modulus, incremental energy density, and fracture assessment value were recorded for each test. The average values achieved from the tests are listed in Table 1.

4. Conclusions

One lot of Aerojet 3744 lot no. 8194D, three lots of Thiokol high-energy gun propellants, and one production lot of JA2 were tested for mechanical response at ambient pressure while conditioned at 21°, 63°, and −32 °C. The materials were tested in uniaxial compression to ~50% end strain using a deformation rate of 1.50 m/s.

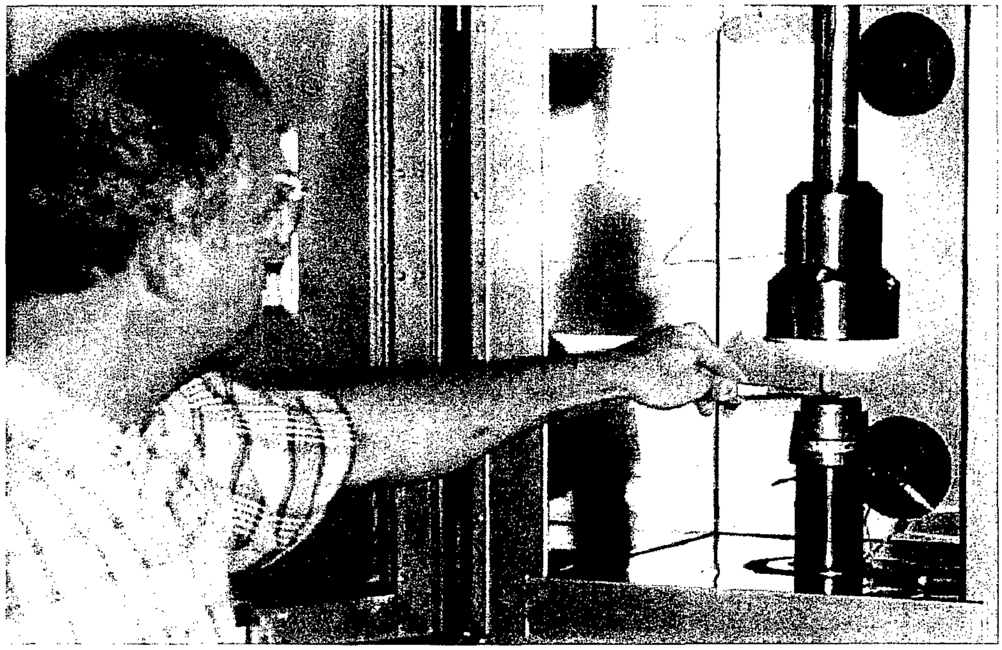

Figure 3. Preparing to test energetic material using high-rate load frame.

At 21 °C, the Aerojet lot, Thiokol lots, and the JA2 lot all showed good response to uniaxial compression. The positive failure modulus values achieved indicated each lot's abilities to sustain load beyond 50% strain. Note the stress vs. strain plot (Figure 4) shows the JA2 lot workhardening beyond 50% strain. The tested specimens (Figure 5) suffered permanent deformation with minimal fracturing.

At 63 °C, again, the mechanical response of all lots were quite good. The Young's modulus values showed some "softening" as a result of the higher testing temperature, as would be expected. The stress/strain plot (Figure 6) shows all lots able at sustaining load. The tested specimens (see Figure 5) again showed very minimal axial fracture and deformation.

At -32 °C, the tested specimens (see Figure 5) suffered moderate amounts of axial and shear fracture; however, the core area of the tested specimens remained mostly whole. Note the stress/strain plot at -32 °C (Figure 7) shows the JA2 lot able at sustaining load and workhardening up to 50% strain and thus the only lot yielding a positive failure modulus value. The Thiokol lots showed more strength at yield than the Aerojet lot.

Overall, each material's mechanical response at 21° and 63 °C was quite good. At -32 °C, the JA2 lot was clearly the better material, followed by the Thiokol and Aerojet lots.

Table 1. Mechanical properties of Aerojet, Thiokol, and JA2 lots at 21°, 63°, and -32 °C.

Lot	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure Modulus[a] (GPa)	IED[b] (MPa)	FAV[c] (MPa)
at 21 °C						
Aerojet 3744 Lot 8194D	17.60	13.32	0.251	0.0034	11.60	1AB
Thiokol Lot JA-1835-01	37.02	7.75	0.642	-0.0271	8.31	1AB
Thiokol Lot JA-1835-02	31.28	8.01	0.502	0.0311	7.87	1AB
Thiokol Lot JA-1835-03	35.33	14.05	0.346	0.0177	7.10	2AB
JA2 Lot HCL93J014001	16.87	4.56	0.722	0.0523	5.37	1B
at 63 °C						
Aerojet 3744 Lot 8194D	7.74	11.05	0.094	0.0046	1.54	1AB
Thiokol Lot JA-1835-01	13.81	10.33	0.202	-0.0212	2.76	1B
Thiokol Lot JA-1835-02	12.58	14.12	0.122	0.0067	2.30	1B
Thiokol Lot JA-1835-03	12.03	17.55	0.085	0.0071	2.20	1B
JA2 Lot HCL93J014001	8.86	4.59	0.244	0.0290	2.57	1B
at -32 °C						
Aerojet 3744 Lot 8194D	67.56	7.73	1.78	-0.260	13.07	5AS
Thiokol Lot JA-1835-01	111.91	7.03	2.79	-0.352	19.88	5AS
Thiokol Lot JA-1835-02	106.43	7.12	2.15	-0.220	19.40	5AS
Thiokol Lot JA-1835-03	108.35	7.05	2.38	-0.180	21.41	6AS
JA2 Lot HCL93J014001	54.03	7.09	1.61	0.067	13.82	5AS

[a]The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (i.e., negative value indicates the material is unable to sustain load). A positive value indicates a positive failure slope (i.e., the material is better able to support load after failure).

[b]The incremental energy density (IED) value reported is the amount of energy per unit volume absorbed at 25% strain; this includes a portion of the area located beneath the stress/strain curve.

[c]The tested specimens were assigned a fracture assessment value (FAV). The values range from 0 (no observed fracturing) through 9 (severe fracturing observed). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, R = radial splitting (i.e., 9A indicates the tested specimens showed a severe amount of axial fracture).

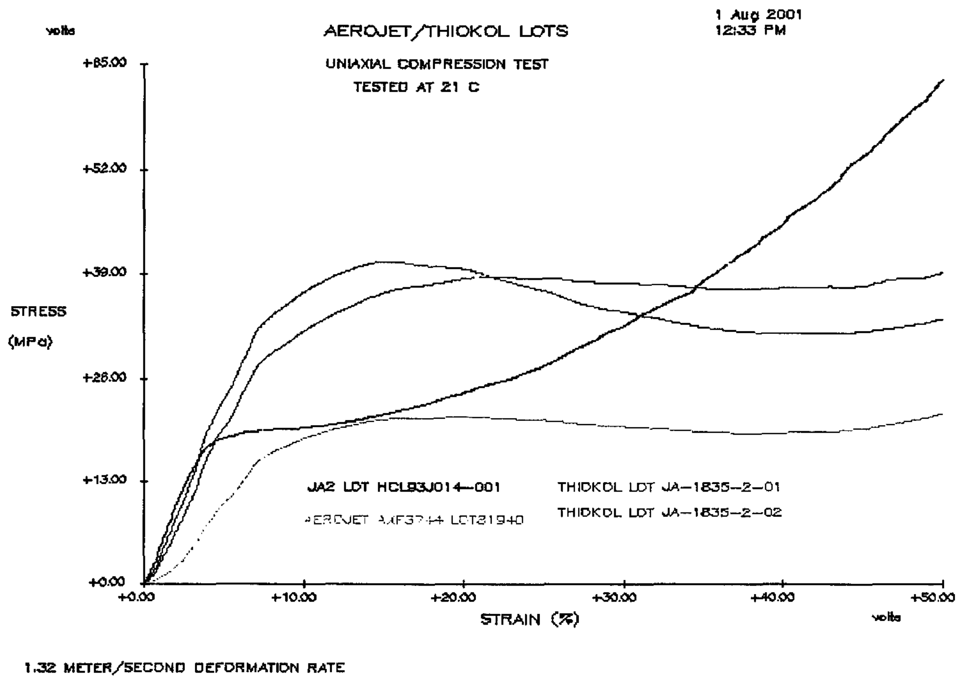

Figure 4. Stress vs. strain plot of Aerojet, JA2, and Thiokol propellants tested at 21 °C.

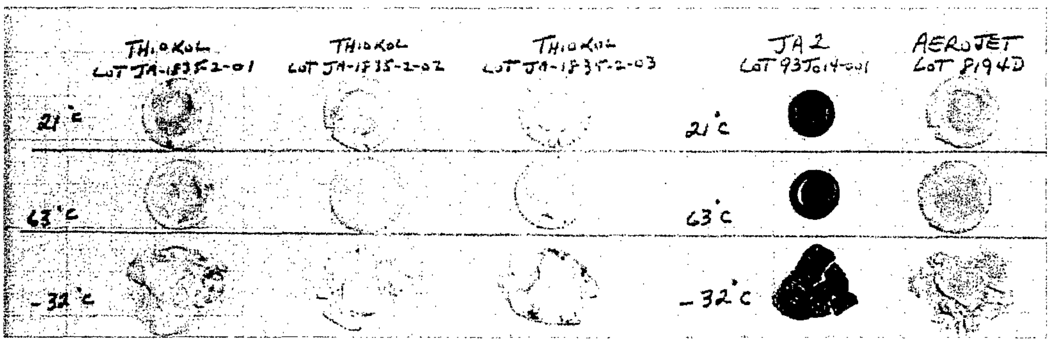

Figure 5. Remains of specimens tested at 21°, 63°, and -32 °C.

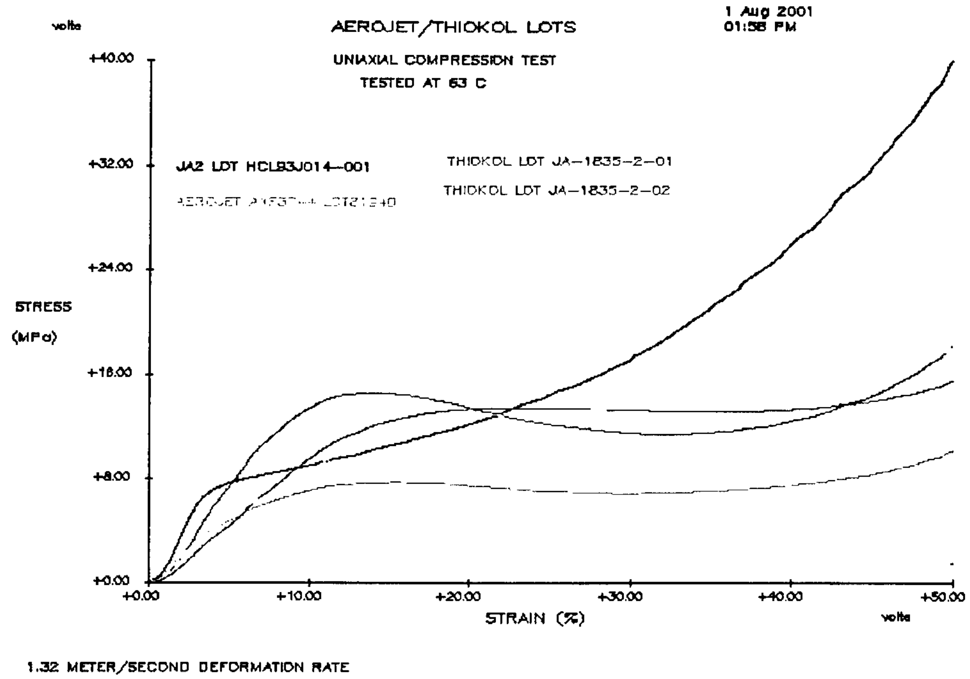

Figure 6. Stress vs. strain plot of Aerojet, JA2, and Thiokol propellants tested at 63 °C.

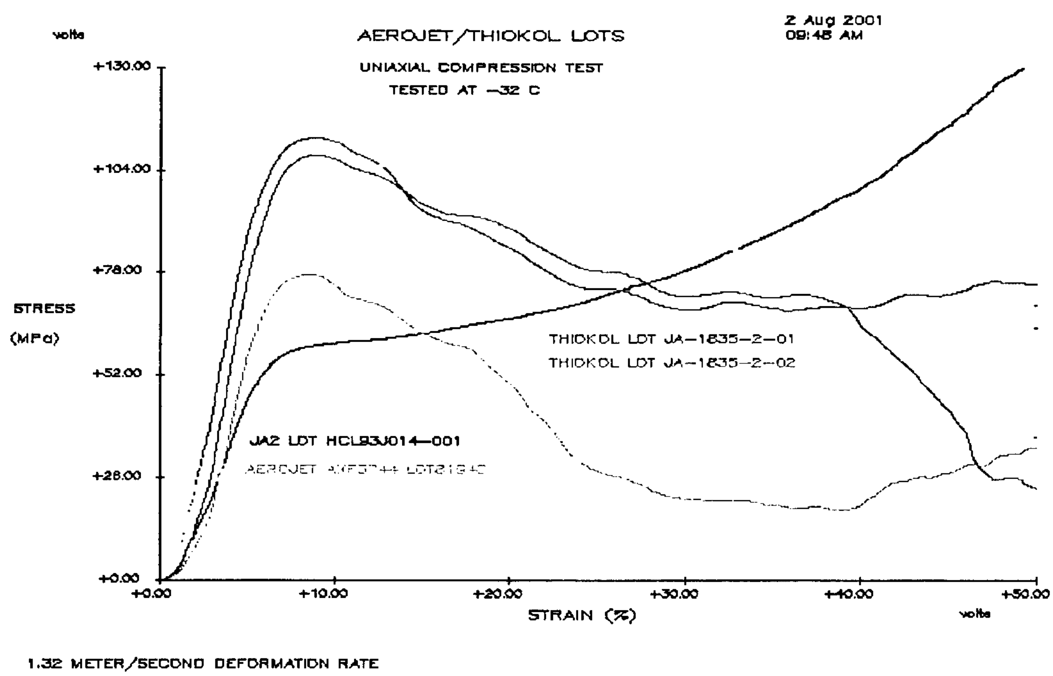

Figure 7. Stress vs. strain plot of Aerojet, JA2, and Thiokol lots at -32 °C.

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13. ABSTRACT*(Maximum 200 words)*

Five lots of high-energy gun propellants were tested in uniaxial compression at temperatures of 21°, 63°, and −32 °C. The materials were taken to ~60% strain using a deformation rate of 1.5 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

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